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FLEXIBLE COMPRESSION MEMBER FOR A FLEXIBLE PNEUMATIC STRUCTURAL ELEMENT AND MEANS FOR ERECTING PNEUMATIC ELEMENT STRUCTURES

The present invention pertains to a pneumatic structural element in the form of an elongated air-tight hollow body that can be subjected to pressure and comprises at least one compression member extending along the hollow body on the load side and at least two tight tension elements that are helicoidally looped around the hollow body in opposite directions. In this case, the tension elements begin and end at node elements arranged on the ends of the least one compression member and are looped around the hollow body at least once.

Pneumatic structural elements of this type are generally known, for example, from WO 01/73245.

In this case, the pneumatic structural element consists, for example, of a flexible gas-tight hollow body that is reinforced with a textile material. At least one dimensionally stable compression member extending along a surface line is arranged on the outer side of this hollow body in such a way that it is supported by the hollow body and cannot buckle. Two tension elements are fixed on the ends of this compression member, wherein said tension elements are helicoidally looped around the essentially tubular hollow body once in opposite directions and intersect on a surface line of the hollow body that lies opposite of the compression member, namely in the longitudinal center of the hollow body. Node elements are situated at the locations at which the compression member is connected to the tension elements, wherein the bearing forces are also introduced into said node elements.

The pneumatic structural element disclosed in WO 01/73245 has various disadvantages that manifest themselves in

practical applications: in order to transport and install the compression member, the excessive length thereof makes it necessary to disassemble the compression member into individual parts that are, for example, butt-jointed at the construction site. This also requires the insertion of the individual parts into brackets provided for this purpose. The installation and tightening of the tension elements also needs to be carried out at the construction site in this case. Since the tension elements and the compression members need to be installed into corresponding node elements suitable for absorbing tensile forces, compressive forces and bearing forces, the installation expenditures at the construction site are comparatively high.

The present invention is based on the objective of developing a pneumatic structural element that can be erected at a construction site without noteworthy installation expenditures.

This objective is attained with the characteristics disclosed in independent Claims 1, 14, 15 and 18, wherein advantageous additional developments of the invention form the objects of the remaining claims.

The object of the invention is described in greater detail below with reference to the enclosed figures.

The figures show:

Figure 1a, a cross section through a flexible pneumatic structural element according to the invention in the deflated state;

Figure 1b, the pneumatic structural element according to Figure 1a with a first embodiment of a compression member in the pressurized state;

Figure 2, a side view of a pneumatic structural element in the empty, rolled-up state;

Figure 3, a cross section through a second embodiment of a compression member;

Figure 4, a cross section through a third embodiment of a compression member;

Figure 5, a cross section through a fourth embodiment of a compression member;

Figure 6, a variation of the fourth embodiment;

Figure 7, a side view of a node element with a compression member;

Figure 8, a cross section through a fifth embodiment of a compression member;

Figure 9, a cross section through a sixth embodiment of a compression member;

Figure 10, a side view of a node element with two compression members;

Figure 11, an isometric projection of one exemplary application for the flexible pneumatic structural element according to the invention;

Figure 12, an isometric projection of a flexible pneumatic structural element with a connecting element;

Figure 13a, a side view of two pneumatic structural elements with a connecting element in the slack state, and

Figure 13b, a side view of two pneumatic structural elements with a connecting element in the pressurized state.

Cross sections of the flexible pneumatic structural element according to the invention are illustrated in Figures 1a, b, namely in the slack state in Figure 1a and in the pressurized state in Figure 1b. The pneumatic structural element consists of a flexible shell 1, onto one side of which a compression member 2 in the form of a flexible plate of compression-proof material is attached over its entire surface, for example, by means of bonding. The shell 1 consists, for example, of a plastic material that is reinforced with a textile material and bonded or welded shut in a gas-tight fashion. Another embodiment of the shell 1 can be realized by embedding a gas-tight tube of an elastic plastic material--for example, polyurethane--in a tube of a textile material with limited stretchability--for example, aramid fibers.

In the deflated state, the compression member 2 is essentially flat such that the pneumatic structural element can be rolled up and transported in the rolled-up state as shown in Figure 2. When the deflated and slack--and possibly rolled-up--pneumatic structural element is filled with compressed air via a valve 3, it initially unrolls and slowly assumes the cross-sectional shape shown in Figure 1b in the unrolled state, in which it is still slack. During this process, the compression member 2 is bent into the functional shape of a cylinder segment shown in the figure. The stability of the elastically bendable compression member in its functional shape essentially has two reasons: first, the bent functional shape increases the geometrical moment of inertia of the compression member. Second, the compression member is supported radially referred to its longitudinal axis on a pneumatic spring due to the interaction with the tension elements and the pressurized

shell 1, i.e., the compression member is not freely suspended between its ends. The buckling load of the compression member is significantly increased due to the higher geometrical moment of inertia in connection with the support of the compression member on a pneumatic spring. A tangential stress σ_u is simultaneously built up on the shell 1, wherein the following applies:

$\sigma_u = p \cdot R$ [N/m]

p = internal pressure of the pneumatic structural element [N/m^2]

R = radius of the pneumatic structural element [m]

The adhesive connection between the compression member 2 and the shell 1 causes this tensile stress σ_u to be transmitted onto the compression member 2, namely in such a way that the compression member is also stressed to σ_u. This additionally increases the geometrical moment of inertia of the compression member, as well as the buckling load.

Variations for designing the compression member 2 and for increasing the buckling load are illustrated in Figures 3-6. In the variation shown in Figure 3, the compression member 2 is arranged within a flexible shell 1 and consists of a gas-tight hollow body 4. Analogous to the embodiment shown in Figures 1, 2, this hollow body is elastically bendable, but also able to absorb longitudinally directed compressive forces. The hollow body 4 is composed, for example, of two plates 6 with the aforementioned properties that are flatly bonded or welded to one another along their edges. If the hollow body 4 is pressurized by means of a pressure medium until a pressure p_1 is reached and the pressure in the interior of the flexible shell is adjusted to $p_0 < p_1$, the tubular compression member produced by the hollow body 4 is able to absorb longitudinally acting compressive forces without buckling.

Figure 4 shows another means for increasing the geometrical moment of inertia of the compression member 2. Alternatively to Figure 1, the--initially--flat compression member 2 is arranged in the interior of the flexible shell 1, namely by means of welding or bonding. A web 7 is hinged to an elastic joint 5 that centrally extends over the entire length of the compression member. In the non-pressurized state of the pneumatic structural element according to the invention, the web 7 lies essentially parallel to the plate 6 of the compression member 2. A plurality of filaments 8 transversely extends through the flexible shell 1; in the non-pressurized state of the flexible shell 1, the filaments 8 remain loose. In the pressurized state of the flexible shell 1, however, the filaments are tightened to such a degree that the pressure built up in the flexible shell 1 causes the web 7 to be displaced from its original position into the position shown in Figure 4, in which it essentially stands vertically on the plate of the compression member 6.

Figures 5 and 6 show two variations of another arrangement for increasing the geometrical moment of inertia. In both variations, several flexible and gas-tight tubular shells, for example, five shells 9, are placed on and attached to the plate 6 of the compression member 2. Equally flexible plates 6 are inserted into the shells 9 and connected to the respective shells 9. When the shells 9 are subjected to pressure, the plates 6 are bent up such that the geometrical moment of inertia of the compression member 2 shown in Figures 5, 6 is increased. The difference between Figures 5 and 6 can be seen in the arrangement of the thusly designed compression member 2: the compression member is arranged outside the flexible shell 1 in Figure 5 and inside the flexible shell in Figure 6. Consequently, the condition $p_1 > p_0$ also applies to the embodiment according to Figure 6.

Although not illustrated in the figures, the invention also makes it possible to utilize a multilayer shell 1. The scope of the invention also includes embodiments, in which the compression members are arranged between different layers of the shell 1.

Figure 7 shows a first embodiment of a node element 11. The effects of the bearing force, the compressive force in the compression member 2 and the tensile forces in the tension elements 12 are vectorially reduced to zero. The node element 11 shown contains a deep eye 13 for being non-rotationally anchored in a (not-shown) support construction. The node element 11, the compression member 2 and the tension elements 12 are connected to one another with conventional means known from the field of mechanical engineering.

Figure 8 shows a pneumatic structural element with two compression members 2 that are arranged along opposite surface lines of the flexible shell 1. The characterizing features described with reference to Figures 1a, b also apply in this case--with the exception of the second compression member 2. A thusly designed pneumatic structural element is provided with at least one pair of tension elements 12 per compression member 2, wherein the tension elements are respectively looped helicoidally around the pneumatic structural element at least once in opposite directions. The arrangement of eyes 13 naturally can be adapted to the respective requirements as long as the zero-sum condition is fulfilled. For example, the eyes 13 may also be arranged such that the longitudinal axis of one eye 13 intersects the longitudinal axis of the pneumatic structural element or lies below this latter longitudinal axis.

If a pneumatic structural element with two compression members 2 needs to be realized in accordance with the

embodiment shown in Figures 3, 4, 5 or 6, it is possible to simply provide two compression members designed in accordance with these embodiments as shown in Figure 9: in this case, a double arrangement of the compression member 2 with the hinged web 7 is provided. The opposing web 7 rather than the surface line facing the compression member 2 is used as the connecting point for the filaments 8 that move the webs 7 into the upright position under the influence of the pressure medium. The features of the pneumatic structural element described with reference to Figures 1a, b and 2 consequently are also achieved in this case.

An embodiment of a node element 14 for receiving two compression members 2 is shown in Figure 10. The compression members 2, at least one pair of tension elements 12 per compression member--and naturally the flexible shell 1--as well as devices for absorbing the bearing forces, for example, the eyes 13, are combined in this node element. The arrangement of the eyes 13 once again has a purely exemplary character and should not be understood in a restrictive sense.

Figure 11 shows the utilization of several pneumatic structural elements according to the invention, for example, as shown in the Figure 10, for constructing a pneumatic and essentially self-erecting element structure, in this case a framework for a roof. In the embodiment shown in Figure 11, 18 pneumatic structural elements of essentially identical design are suitably connected to one another. This is realized, for example, with the connecting elements 15 that are shown in Figure 12 and described further below. Several pneumatic structural elements can be combined in such a connecting element 15 with their node elements 14 or in an actual node.

In the embodiment shown in Figure 11, three to four pneumatic structural elements are respectively connected in one connecting element 15. The ends of the pneumatic structural elements that stand on the ground in Figure 11 may be equipped with a shoe instead of a node element 15. The element structure according to Figure 11 can be covered with a suitable canvas or tarpaulin either before or after its erection. Figure 12 shows an embodiment of the connecting element 15 that serves for connecting four pneumatic structural elements. These pneumatic structural elements may be realized with two compression members 2 as shown in Figure 12. The lower eyes 13 can be eliminated in an embodiment with only one compression member. Four eyes 16 are provided per pneumatic structural element to be connected, namely two respective eyes in the form of a coaxial arrangement, through which a bolt 17 is inserted.

The connecting element 15 may be realized in the form of a welded sheet metal construction or a casting.

The angle between two flexible pneumatic structural elements in their functional shape can be defined by the arrangement of the upper eyes 16 relative to the lower eyes. This also defines the outside contour of a structure composed of flexible pneumatic structural elements.

Figures 13a, b show steps for assembling such a structure: two pneumatic structural elements are connected to a first connecting element, for example, the connecting element in the gable of the structure shown in Figure 11, with the aid of the bolts 17 after the still slack pneumatic structural elements were unrolled. Other connecting elements and pneumatic structural elements can be installed in the same step. The pneumatic structural elements are then pressurized such that the compression members assume their functional shape. Consequently, they are able to absorb the moments built up in the connecting elements such that the

entire structure is erected as indicated by the corresponding arrows in Figure 13b.